MUSEUM OF PRACTICAL GEOLOGY.

Government School of Mines and of Science applied to the Arts.

ON THE

SCIENCE OF GEOLOGY

AND ITS APPLICATIONS,

(BEING THE INTRODUCTORY LECTURE TO THE COURSE OF GEOLOGY, SESSION 1851—1852.)

BY

ANDREW C. RAMSAY, F.R.S.

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Centuries have passed since some of the more obvious of geological phenomena first began to attract the attention of a few of the early cultivators of natural science; but it was not till after the revival of literature in Europe, that some of the subjects contained in the wide field of theoretical geology began to be actively canvassed by many bold and inquiring spirits. For nearly three hundred years numerous authors touched upon the subject in their writings, or devoted elaborate treatises to its illustration: the works of such men as Fracastoro, Leonardo da Vinci, Steno, Scilla, Colonna, Moro, and Generelli, in Italy; of Palissy and Marsilli, in France; of Raspe and Fuchsel, in Germany; of Woodward, Ray, Hook, Strachey, and Mitchel, will ever be interesting to the student who delights to trace the early development of the science: and though its progress was slow, (down almost to the time of some of the living fathers of a more advanced geology,) yet great was the benefit it derived from the interest excited by the continuance of speculation, whether true or false. Few believed, yet little by little some scattered truths were elicited, which by degrees prepared men to throw aside the prejudices that restrained them from grappling with the subject in the only manner that could ensure its full development. For geology was not so fortunate as chemistry, when princes vied with each other in the encouragement of alchemical discovery. There was no heresy in the transmutation of baser metals into gold. Geology, on the contrary, was for long generally esteemed a pestilent heresy, and though its cultivators escaped the prison, yet, even to our own day, a few angry men are not found wanting, who, steeped in ignorance or a mistaken zeal, still re-echo the time-worn cry. For all purposes of the continuance of error, that time has however passed away, and educated people

cease to regard as dangerous, and the disturbers of truth, those who follow to the utmost the legitimate investigations in physics and natural history opened out by the comprehensive labours of the geologist.

No science, save chemistry, has in the same short time made such rapid advances as geology. While the former began to assume its true position under Black, Cavendish, Priestly, and Lavoisier, geology received a new stimulus in the grand generalization of Werner, Hutton, Cuvier, and Smith; and of late years so rapid and wide-spreading has been its progress, that no single mind can grapple with all the details of its numerous branches.

Of these the chief are :—

1st. Physical geology.
2nd. Palæontology.

The first deals with the nature and modes of formation of rocks, such as the laws that regulate and have regulated the origin and manner of distribution of strata, the nature of subterranean heat, its present and past effects beneath the surface of the globe, and the exterior igneous phenomena dependent on its operation; the disintegration, slow movements, or more violent disturbances traceable to these, or other causes, of which the present configuration of land and water is the sum; and the means consequently yielded by these apparent breaks in the continuity of order, of demonstrating the law of the superposition of strata, and of succession in geological time.

Here it is that palæontology, or the history of the old life of the world, comes to our aid. The time is not very far removed when, under such names as glossopetræ, cockles, and petrifactions, those wonderful organisms that abound in rocks, were confounded by the curious with crystalline and other mineral substances; and though Hook had hinted at, and Fuchsel almost pointed the way, it was not till William Smith clearly enunciated the doctrine of the characterization of masses of superimposed strata by distinct groups of fossils, that their study acquired that scientific value by means of which the geologist is enabled to identify groups of strata, though broad oceans roll

between. Miscellaneous heaps of organic remains, collected without reference to their geological locality, have no longer any beyond an accidental value to the scientific geologist, nor can an earnest worker in the broader fields of the science now afford to consider the labours of the fossil naturalist as extraneous to his object. They are indissolubly linked together; the evidence afforded by each is indispensable to the other; and though a man may be a geologist without being thoroughly versed in palæontology, yet if he wish to qualify himself for work, whether economic or theoretical, that may extend beyond the petty details of merely local workings, he will find it needful to be acquainted at least with the principles of palæontology, and to familiarize himself with the general groupings of the organic forms preserved in the larger subdivisions of the strata that form by far the greater proportion of the rocks composing the crust of the earth.

So also in mineralogy, a science that by many has been looked on as a mere branch of geology. Viewed in such a light, geology being the history of the earth, animate and inanimate, we might well ask, how many are the material sciences that do not, directly or indirectly, spring therefrom? No man considers comparative anatomy a mere branch of geology. Nevertheless it is an essential ally. So is it with mineralogy, the modern progress of which rather throws it into the domain of physics and chemistry; for, though the natural substances with which the mineralogist deals all form parts of the crust of the earth, they yet include many a form that rarely or never comes under the observation of the geologist. Still, the exterior mass of the earth being formed of minerals in one state or another, the study of mineralogy is indispensable to the geological student.

The same may be said of chemistry, which now begins to throw a little light on some of the more obscure problems of geology; as, for instance, the metamorphism of rocks, and the theory of volcanos; a fine example of which may be cited in the beautiful investigations of Professor Bunsen, in Iceland, where some of the chemical processes consequent on volcanic action may be studied on the spot, thus aiding in the explanation of phenomena exhibited in volcanic districts of all geological ages.

The true bearing of the first part of these observations at once becomes apparent when applied to a passage in the history of geology. Before the time of Werner, more than a century was required to elicit the scattered facts and generalizations deduced by previous observers. Of Werner it might be said, that "his merit consisted in this, that he infused into the body of the science a new spirit."* The breadth of his views respecting the universal superposition of strata, his application of their structure to mining, and the eloquent sincerity with which he advocated his doctrines, raised an enthusiasm that spread over the continent of Europe, and gained numerous disciples to the cause.

This, perhaps, more than counterbalanced the prejudice suffered by our science in the promulgation of the erroneous hypothesis that the ancient rocks of every description were successively deposited over the whole earth, from aqueous suspension or solution in a "chaotic fluid." The very excitement roused by the bitter controversy maintained between the followers of Werner and the more philosophical disciples of Hutton, brought constant accessions of inquirers into the field, whose opinions, right or wrong, kept up a continued interest in the subject, till, weary of controversy, the very keenest advocates of the most exclusive Wernerian theories began to see the necessity of grounding their speculations on a more rigid examination of facts.

Of all the men that have heretofore illustrated the science of geology none is greater than Hutton, whose name was so long used as their watchword by the opponents of the Wernerians. He at once threw aside the minor proofless speculations with which older writers bewildered their readers, and by the strict union of observation and generalization, his comprehensive mind grasped the main outlines of the physical section of the subject, and brought geology within the pale of inductive reasoning. Not a scrap of illustrative map or section, and but little of local description, accompanies Hutton's "theory of the

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* Liebig's Letters on Chemistry, 1851. p. 26. Said of Lavoisier.

earth;" and therefore, (harmonizing as they do with the detailed field work of later geologists,) his generalizations read almost as if dictated by a prophetic spirit—an impression not diminished by his massive and somewhat obscure diction. There wanted but one discovery to give that direction to the science which has led to the present high point of knowledge, I mean the doctrine of succession of species in time. Nevertheless, even had Scotland been a country geologically favourable to the easy development of that doctrine, it may be doubted, whether Hutton's mind was so modelled that it would spontaneously have entered on such an investigation. He perceived the great truth, that from the waste of continents, broad and thick contemporaneous deposits, containing the relics of life, are being formed in the seas, and that in all traceable past time the same laws have prevailed; but he knew not of the existence of a rule by which, independently of mineral character, contemporaneous strata may be identified, although widely separated from each other. The germ of this truth is, indeed, contained in the writings of an earlier writer (Fuchsel); but when he lived, the progress of discovery had not sufficiently prepared the way for its reception; and it is to the independent observations of that "great original discoverer" William Smith, that we owe the first clear enunciation of the law of the stratigraphical succession of species—a law alike great in theoretical results and in the strictly practical applications arising therefrom.

In the whole history of geology there is no chapter more touchingly interesting than the manner in which Smith arrived at his conclusions. From the moment the light first dawned on him, he never ceased to follow his convictions, with unflagging patience, industry, and energy, full of enthusiasm, undaunted by difficulties, or by the little heed that for many years was paid him by the celebrated men, the results of whose subsequent work are in great part based on his discovery. "It plainly appeared" to him, that his "was to become a system of experimental philosophy that would embrace the whole surface of the globe."* Homely in exterior and manner, ungifted with the

* Phillips's Memoirs of Wm. Smith, p. 10.

power of eloquent description, and averse to the labour of reducing his ideas to writing, few of his contemporaries would have dreamed of ranking William Smith as a man of genius: but posterity disregards externals, and judges men by their works; and I reverentially believe that in the truest sense of the term he well deserves the name. His clear-sighted sagacity, foreseeing the immediate application of local observations to world-wide areas, arose from a high combination of observing, inductive, and speculative powers—a combination of which the highest scientific genius is composed; his unswerving devotion, holding all other objects subservient to one great end, the heroic indifference with which he regarded all personal interests except in so far that they furthered it, his indomitable perseverance in the midst of difficulties and delays that hindered the production of his map of the English strata, all mark a man well worthy to be the first enunciator of a truth which in its consequences has opened to view a wide field for investigation that till his time lay utterly unapproachable. This grand and simple law, wedded to various branches of physical geology, already begins to "embrace the whole surface of the globe." This is what we are now doing. The "after ages" have already begun, when, as he predicted, we shall "get a tolerable description of the habitable world;" and on the further progress of this work of identification of strata, of mapping and of section making, depends at present most of the advancement of correct geological theory.

And here I would remark, that the results deducible from Smith's discovery afford another pregnant example of the economic application of purely theoretical principles, which in their first conception seemed but little connected with the furtherance of our material prosperity. In the expressive language of one of my colleagues, "it is but the overflowings of science that thus enter into and animate industry"—a truth in the department of geology that I shall have occasion to illustrate in the sequel of this Lecture.

The right understanding of the law of superposition is not of value only to the man of science: it is important to every speculator in mines, to every landed proprietor who cares to understand the mineral value of his property; and the principles

and greater laws pertaining to geological phenomena are now so distinctly understood, that there is no difficulty in imparting them to others. To draw an illustration from astronomy: we all know the truth of the revolutions of the planets and their satellites, of their general relations to the sun, of his relation to the fixed stars, of their motions in space, and of the dependence of their movements on the law of gravitation. Every well-informed schoolboy knows these things. We cannot all demonstrate them, but we believe in their demonstration; not alone that they do not contradict our experience, but principally by virtue of our faith in the men who have possessed a knowledge sufficiently high to solve the problems. Is it because geology as a science only numbers hundreds of years where astronomy numbers thousands, that beyond the pale of the student so much ignorance prevails regarding the simplest elementary principles and laws of the science, and that its cultivators are by many still looked upon as mere speculators; or, worse still, that others fancy themselves licensed to theorize without a particle of preliminary geological knowledge? Certainly not: true chemistry is but little older than geology; and no man fancies himself a chemist because he can *see* substances that enter into combination with each other. Not so with geology; without study, without training, without extended observation, and almost without reflection, many a man fancies himself qualified to decide on the nature and disposition of rocks (because they are before his eyes), whose decision is utterly worthless. If the leading features of astronomy are easy of comprehension, those of geology are more easily demonstrated, and but little less easy of understanding; the doctrines of superposition of strata, of succession of species in time, of disturbance of beds and consequent unconformity, these and all other simple problems might (did there exist a race of qualified teachers) be made a part of every well-advanced schoolboy's education. Then, at all events, ignorant or mistaken men, misnamed practical, could not so readily delude the credulous or unwary into ruinous speculations: the iron-charged water of a spring, the colour of a rock, or the mere association of limestone and shale, might cease to induce explorations for coal among those who, hastening to acquire

wealth, too often only precipitate their ruin; and I earnestly hope and believe, that not only by the aid of this School of Mines, but also by the more general spread of scientific education throughout the land, much may be done to prevent the frequent recurrence of so great a waste of energy and capital. To this particular end the more general diffusion of such authentic documents as the Government maps and sections will in time materially contribute, and much capital now wasted be skilfully applied, or diverted into other channels.

In Phillips's life of Smith several interesting notices are given of fruitless trials for coal in the Oxford clay, near Oxford and Wincanton. That at Wincanton was persevered in against the strong remonstrances of Smith. And here, instead of assuming a complete acquaintance in each of my audience of all the facts that bear on such cases (of which I shall cite other examples), you must permit me to explain one or two points that properly belong to a more advanced part of my course, but which it is now needful to point out for the full understanding of the subject.

I have alluded to the fact that the principal masses of strata were each in succession accumulated in sea bottoms; and these accumulations were composed of various sediments, just as at the present day quantities of mud, sand, and shingle are borne by rivers from the land, or torn from coasts and spread abroad on the floor of the ocean, to become the tombs of the creatures and plants that inhabit it. These beds have been, according to varying conditions, more or less consolidated, partially heaved above the waters, dislocated, invaded by igneous products, disintegrated, and denuded, their materials being often re-employed in the formation of later strata. And this process has been the course of nature through all traceable time. Hence it follows that the rocks of continents and islands formed by such disturbances are necessarily of earlier date than the strata constructed from their wreck, and deposited in the surrounding seas; and the unconformity of one set of rocks to any other set will be proportionate to the amount of disturbance of the strata so upheaved, denuded, and often deeply depressed beneath newer accumulations. This unconformity was, as early as 1669, alluded to by Steno in his Prodromus, in which, by a

series of rude diagrams, he sought to prove that the "country of Etruria hath been twice fluid, twice plane and dry, and twice scabrous and craggy." Strachey also had a faint knowledge of this fact as exhibited in his diagrams of the unconformity of the coal measures and new red sandstone of Somersetshire.* Our illustrious Hutton was, however, the first geologist who clearly expounded the laws of unconformity, and proved their universal application.

How, then, do these truths bear on the question, when, as in the instance recorded by Smith, sinkings were begun in the Oxford clay, the dark coal measure colour of which deceived the speculators and prompted the experiment? In the first place it is perfectly known, that excepting in the coal measures no coal occurs in any other formation in this and the surrounding districts. The sinkers knew this, for when they reached the oolitic limestones they abandoned the attempt. At what depth, then, had they persevered, might the true coal measures have been found? There is little reason to doubt that it would have been necessary to have sunk through oolitic and other rocks, (too thick to permit of such a speculation being profitable,) at the very least from 1,500 to 1,800 feet.

But even then there would have been no certainty of reaching the coal measures, for the newer rocks rest unconformably upon the older strata, and it is not improbable that owing to earlier disturbances other beds beneath the coal may rise towards their base at the point beneath the shaft.

It is forty years since this incident occurred. There are now sparsely scattered throughout England mining engineers of high attainments, well versed in the principles of geology; and the science is reaching a point when problems in economics may be solved far more obscure than those that tasked the knowledge of Smith; but you must not therefore suppose, that, as a general rule, many of our proprietors and speculators are guided by a higher knowledge than then prevailed. Such is not the case. Throughout the length and breadth of the land, down to this very day (as I have already stated), equally fruitless and still

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* Philosophical Transactions, vol. 33. p. 395.

more absurd undertakings are constantly being entered upon. I shall cite several other instances.

Sir Henry de la Beche has informed me, that near Tiverton, in Devonshire, many years ago, a shaft was sunk in the shales of the millstone grit, an unprofitable set of beds at the base of the coal measures. As might have been foretold, nothing was found, till one Sunday, when the population were safely housed in church, some boys emptied a coal-scuttle into the pit, and on the top threw in part of the extracted rubbish. Great was the joy on Monday morning when the miners brought up the coal: it was declared to be "as good as Newcastle" (which indeed it was), and all the parish bells were set a-ringing!

On Chard Common, near Lyme Regis, they bored in the lias for coal, at an expense of several thousand pounds. The deception was fostered by the accident of passing through—not a *bed* but a *piece* of lignite. Numerous lias fossils were turned out, which of themselves ought at once to have decided the question, even without a broader knowledge of the geological structure of the country.

A similar trial took place at Kingsthorp, near Northampton, where a shaft was sunk through the lower oolite and lias, at an expenditure of near 30,000*l*. The adventurers desisted when they reached the new red sandstone. Many similar instances might be multiplied.

In the coal-field of the Forest of Dean the carboniferous limestone shale lies 1,000 feet beneath the lowest bed of coal. Nevertheless, in Herefordshire, a person, more confident than sagacious, first built his engine-house, and sheds to receive the produce, and then boldly sunk a shaft in these beds in search of coal, where it could not by possibility exist. In future lectures I shall show that the coal measures once extended above this area, but the conditions never obtained by which one bed of coal could have been formed either in the beds explored, or in the old red sandstone on which they rest. At the very moment I now write I have received a letter from Mr. Aveline, one of the geologists of the survey, in which he says: "I have a narrow slip of coal measures running between the Permian, the new red beds, and the old red sandstone that you saw at Bewdley. A

person found out the only place where the coal is well shown, and sunk a pit, but finding the coal worthless, *he has gone a little way off on the old red sandstone*, where he is sinking after the most approved manner, bricking his shaft round. He is going through some very hard sandstone." In this case the true explanation, of course gratuitously offered, was disregarded, and the last report announced by the "practical men" was, that they were on the very verge of discovering coal.

Observe in the vertical column, and in this horizontal section, the geological position of the lower silurian shales, utterly barren of coal, and sunk thousands upon thousands of feet beneath the coal measures, carboniferous limestone, and old red sandstone.* They are often black, and carbonaceous-looking, and their oozing springs are sometimes discoloured and scummy by the presence of oxide of iron, and other impurities derived in the passage of the water through the rocks. But coal measure shales are also frequently black, carbonaceous, and charged with numerous beds of ironstone, which, discolouring the springs, produce the red water (dwr goch) of the Welsh miner. By a mistaken application of the principle, that like causes produce like effects, the empirical miner sets to work, and the black slates of the counties of Pembroke, Radnor, and Caermarthen, —of Montgomery, Merioneth, and Caernarvon,—near Trefgarn, Caermarthen, Builth, Llanidloes, in Lleyn, and at Caernarvon, —are dotted with shafts, borings, and levels, sunk or driven in delusive searches for coal. While in progress, the cry still is, "the indications are good, go a little deeper;" and the pit, the disappointment, and the ruin, often deepen together, till, abandoned in despair, the speculator is left to console himself with the parting assurance, "We are not to blame;—had you only gone a little deeper." Long after, when the wandering geologist visits such spots, he is informed that the miners actually found coal, but were bribed to hush it up by coal owners jealous of their markets.

I do not wish to imply that the men who advise such under-

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* Alluding to diagrams on the wall.

takings generally wish to deceive. Ignorance on both sides lies at the base of the enterprise. But on that very account, I repeat, that even a slender amount of science infused into the general education of the country would strongly tend to prevent the unceasing recurrence of such ruinous absurdities. The truly practical man,—the scientific mining engineer,—reasons and advises on very different principles. He is conversant with geological maps and sections; his experienced eye distinguishes the geological relations of the deep and wide-spreading strata of which a country is composed, and as a rule, he knows the utmost limits of the ground where it is safe to adventure; and, further, if he add to this a general knowledge of the organic forms that characterize these formations, a glance will tell him (however black the shale, or ferruginous the water,) that rocks containing certain forms of graptolites, trilobites, lingulæ, and pentameri, were formed untold ages before the commencement of our carboniferous epoch.

It is foreign to my present object to trace the career of Smith in the application of his principles to agriculture, canal engineering, the interception of springs, opening of quarries, or the detailed determination of the position of coal bearing strata, concealed by overlying masses of new red sandstone. The immediate scientific results of his work* you see in this diagram, which exhibits his enlarged and corrected ideas of superposition, as understood by him, in the year 1816, and by this map, published in the previous year. This was the first geological map of England, or, indeed, of any kingdom, ever produced,—a work in those days of extreme difficulty, when we consider that almost all the data were new and collected by himself; and that no large uniform topographical maps of authority then existed on which to depict them. Though propositions were made to the Government of the day, it yielded him no aid; the arduous work, wonderful in its kind, was accomplished by his own individual efforts; and it was not till many years later that, recognizing the national importance of a

* Smith's Column and Map.

truly accurate survey on an adequate scale, Government established, under the direction of Sir Henry de la Beche, a geological survey of Great Britain in connexion with the Board of Ordnance. The survey then established, and since extended to Ireland, is now in full operation under the department of Works: the local direction for Ireland has been entrusted to Mr. Beete Jukes; the survey of England and Scotland is entrusted to my care, both being subject to the control of Sir Henry de la Beche as Director General. The basis of the survey is the Ordnance maps. A specimen of a portion of the work executed in England and Wales hangs on the wall, and when a sufficient area has been topographically surveyed, and other needful arrangements made, the survey will commence operations in Scotland.

On this extended scale, with a correct topographical basis to work upon, it is evident that a skilful geologist can lay down a multitude of facts in a style that, both for accuracy of general outline, and minuteness of detail, was formerly undreamed of by geologists; and I think I may be permitted to say, that great has been the benefit accruing, and yet greater will accrue, from this work, alike scientifically and economically. The boundaries of every formation, and of each of their subdivisions, of every igneous mass, intrusive or bedded, with all their accompanying intricacies of interstratified slates and volcanic ashes, the run of workable slates, of beds of freestone, limestone, and gypsum, every dislocation, metalliferous lode, and outcrop of coal, are traced with all that minuteness of detail admissable on this comparatively extended scale. These are accompanied by enlarged illustrative longitudinal and vertical sections, drawn in *true proportion*. As an instance of their value, I would remind you that the broadest and deepest coal-field in Great Britain is that of South Wales. After the publication of the maps of that country, landowners, coal proprietors, coal viewers, and mining engineers, all acknowledged their importance; and I had the satisfaction of hearing the observation of a gentleman well versed in mining and scientific geology, "that the publication of the Government maps had placed them thirty years in advance of what they were

before." I will be excused from the imputation of attempted self-laudation when I state, that that district was completed principally by Sir Henry de la Beche and Mr. Logan before my connexion with the survey began.

I shall give one other example of the application of geological principles to the solving of a question which will one day be of great economic importance: it is drawn from the work of the geological survey now in progress in the centre of England. As our sections in that country are still incomplete, I can only at present explain the principles on which our conclusions depend by means of diagramatic sections.

Underneath the true new red sandstone on the borders of Nottinghamshire and Derbyshire, is a strip of country noticed by Smith, but first fully described by Professor Sedgwick. He divided its rocks into magnesian limestone, and lower new red sandstone.* These rest unconformably on the coal measures, which they follow in the order of superposition. Owing to differences in lithological character, and the absence of the limestone, the Staffordshire, Warwickshire, and Shropshire coal-fields were for long considered as unsurrounded by these beds. The upper new red sandstone was supposed to rest directly on the coal measures. By degrees, however, their existence in sundry places was noticed or surmised, and now on some of the smaller published maps indications of their existence may be found, both where they are, and where they are not. With a difference they are so exceedingly like the new red sandstone, that they have for the most part been confounded with it, at least by almost all those engaged in the working of mines; and again, in some respects their mineral character here and there strongly resembles certain red portions of the coal measures. They are, therefore, in most maps sometimes incorrectly delineated, but distinguished from,—and sometimes erroneously included in, the coal measures, or new red sandstone, as the case may be.

It chanced, however, last year, that by dint of constant

* The Pontefract rock, of Smith.

practice and study in the field, my colleague, Mr. Hull, discovered a key to the separation of these rocks from any others of the district; and the progress of the mapping of the country has shown, that everywhere, except in accidental cases, they rest unconformably on the coal measures, and that the new red sandstone is unconformable on both.

Now, for reasons that I cannot at present enter upon, it is known to geologists that concealed treasures of coal probably underlie the larger portion of the great area of new red sandstone that surrounds the coal-fields of central England. Already in great part of South Staffordshire most of the best beds of ironstone are being rapidly exhausted; and in great part of the district "the thick coal" has been extracted, or the workings are so drowned by water, in consequence of the faults being worked through by gate-roads, that its drainage is next to impossible. The day will surely come when this and other coal-fields will be worked out; and the question will then arise, at what depths beneath the unconformable covering that shrouds them, will coal-bearing strata be found in various localities? This is an important problem, which the work we are now engaged upon will go far to solve.

By means of numerous observations of the dip of strata, and the construction of sections on a true scale, it is often possible to determine the thickness of any special mass of rocks. Within a given area, where, therefore, is the new red sandstone likely to have the smallest thickness? or, in other words, where can we predict that the concealed coal measures rise nearest to the surface?

In this diagram you will observe that the lower new red sandstone, or Permian strata, rise against the coal-fields on the east and west, and that the whole is overlaid by the upper new red sandstone.* It is therefore to be expected, that in this district, the lower new red sandstone strata intervene between the upper new red sandstone and coal measures throughout. This suspicion is confirmed by the circumstance, that within the new

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* Illustrated by a diagram of the disposition of the strata round the South Staffordshire and Coalbrook Dale Coal-fields.

red sandstone area surrounding the central coal-fields of England, many miles removed from these fields, the beds that elsewhere rest directly on the coal measures are brought to the surface by faults.

If the estimates of thickness be correct, then no wise man would sink in this area on the new red marl, because, before he could reach the coal measures, he would have to penetrate the aggregate thickness of three formations, viz., new red marl, upper new red sandstone, and the lower new red sandstone or Permian.

To the unpractised eye, these last seem ordinary new red sandstone. In this area they were confounded with it. But a rigid geological examination has shown that they belong to a lower set of beds, and that faults at certain points raise them to the surface ; and these may be proper places in which to sink in the hope of finding coal, because the concealed coal measures must also be raised nearer the surface by the faults, and therefore in the search, we escape many hundreds of feet of rock that elsewhere overlie the strata to be sunk in.

There is yet another point of interest in connexion with this subject. I have stated, that the new red sandstone proper rests unconformably on the lower new red strata. It therefore often happens, that overlapping the latter it rests directly on the coal measures. The result is, that at a distance from the carboniferous strata, it is possible to estimate the probabilities as to whether in sinking through new red sandstone, we might reach the coal measures without the intervention of thick masses of lower new red or Permian strata.

These are questions that daily assume a higher importance. The attention of proprietors and miners already begins to be directed to them, hitherto in general without much effect, chiefly for want of accurate geological information. The value of land will be materially affected in certain districts by the information yielded by such maps and sections.

If you compare a distorted section with one across the same country drawn on a true scale, you will readily perceive one of the causes of the indefinite ideas often entertained on such subjects. In one the distances are diminished, the heights

absurdly exaggerated, and the disposition of the strata therefore necessarily falsified; in the other, a true corresponding scale for distance and height being adopted, the lay of the beds as they actually occur in nature is obtained, and the conclusions arrived at are precise and definite. On me devolves the responsibility of instructing the pupils in the School of Mines in the methods by which accurate geological maps and sections are constructed; and it will be my duty to do so, not only in the lecture room, but also through the medium of the districts in progress on the geological survey, to convey practical instruction in field work to those of our mining or engineering students to whom such knowledge may be indispensable.

It would be easy to show many other applications of geology to practical purposes, as, for instance, in the construction of roads, and the selection of material for macadamising, in the engineering of canals by leading them over naturally tenacious bottoms and the avoidance of porous formations, in the selection of minor deviations of lines of railway with reference to cuttings and tunnels, and also in the sinking of shafts. An instructive instance connected with shaft sinking came under the notice of Mr. Bristow of the geological survey. On the Ridgway tunnel a shaft was sunk through 80 feet of sand, which rendered it necessary to brick the sides, whereas a few feet further in either direction would have carried the shaft safely through the chalk. The sinkers had, in fact, chanced to sink in one of those holes in the chalk known to geologists by the name of "pipes." These are always of small diameter, and probably originated in the percolation of rain water, the carbonic acid having carried off the lime in solution; they afterwards became filled with foreign substances, *in* which, in this instance, they sunk. A knowledge of this simple fact would have prevented the blunder.

The agricultural applications of geology have been ably treated by Mr. Trimmer; and its bearings on large supplies of water to towns are beginning to be universally recognized. The country around and beneath London affords a tempting field for enlarging on this subject, but at present I shall rather refer to the construction of the artesian well at Grenelle, principally because it was undertaken and executed on data and principles purely geological.

In earlier times the phenomena of springs gave rise to much discussion. While some considered that they originated in great subterranean reservoirs, others asserted that they were due to the percolation of sea-water which flowed upwards by subterranean cavities, losing its saltness in the passage. More than a hundred years ago, Valisnieri partly explained their dependence on the fall of rain, and the nature and arrangement of the strata through which the water percolates. Since his day, the theory of springs has by degrees come to be well understood, and from the time of Smith, by strict attention to geological data, it has been possible to estimate with almost absolute certainty the results of sinkings in search of underground water in numerous localities.

Rocks are of many degrees of hardness, and variously disposed. Thus, for instance, granite and its igneous allies, are but slightly porous, and it is only through joints and cracks, generally of no great depth, and having little intercommunication, that the surface water can penetrate; and thus the subterranean oozings are isolated, so that generally no great body of underground water is anywhere collected, and numerous feeble springs rise here and there to the surface. But it is different with many of the stratified rocks, which not only by a multiplicity of joints, but also from their extreme porosity, and the sloping disposition of the beds, are often perfectly adapted to the conduction, and partial retention, of large bodies of water, at depths varying with the disposition of the strata.

The nature of artesian wells is simple. If I take a bent tube and pour therein any quantity of water, it will maintain a corresponding level on either side; and if I insert another tube shorter than the curved arms, (we shall suppose at the lowest point of the curve,) then, by virtue of a law of hydrostatic pressure, the water will rise in the inserted tube, an equal amount being displaced in the curved arms on either side. There it will rest. But if a constant supply be yielded to one or both of the openings of the curved reservoir, then the water will overflow at the mouth of the central inserted tube, which thus represents the boring of an artesian well.

The strata around Paris are in a general way very similar to those forming and surrounding the London basin, (as it is often

termed,) with which many of you are familiar. Its highest members are composed of tertiary strata of sand and calcareous sandstone, beneath which are beds of mottled clay. The chalk on which this lies is 1,477 feet thick, resting on 150 feet of green sand, which in its turn lies on the gault. This last is for the most part composed of clay, and nearly impermeable to water. The whole over a width of many miles is arranged in the form of what geologists term a basin, that is to say, the strata from their outcrops have a tendency to slope towards a general centre, where for a space they lie more or less horizontally.

On the margin of the basin, strata of green sand and gault rise to the surface at heights in many places approaching to 330 feet above the sea, Grenelle being only about 100 feet above that level. Geologists knew that the water which fell on these strata at their outcrop would of necessity percolate in the direction of the inclination of the beds, so that, at the lower points of the curvature, a great body of water must exist, confined as it were in a sponge, and unable to escape below, because of the impermeable quality of the beds on which the porous strata rest. This deep-seated reservoir being tapped by boring, the water would rise to the surface in the manner I have explained.

In 1832 the municipal corporation of Paris, impressed with the sanitary necessity of further supplies of water, voted 18,000 francs for the construction of three artesian wells—a sum so ridiculously small that the project was immediately abandoned. M. Mulot, however, one of their engineers, having previously sunk in the chalk at Suresne, at Chartres, and at Laon, to the depth of 1,082 feet, proved that it would be necessary to bore completely through that formation to ensure a sufficient supply. This conclusion, based on strict geological reasoning, was confirmed by M. M. Arago and Walferdin, and in November 1833 the work was begun. With infinite energy, skill, and perseverance, M. Mulot carried it on, overcoming every opposition, physical and moral; for he had not only to conquer those natural difficulties that beset so unexampled an undertaking, but he had also to contend with municipal parsimony, that shrank from the continuance of supplying funds for a project based on purely

theoretical grounds. When he reached the depth of 1,640 feet, at an expense of 263,000 francs, they stopped these supplies; but so great was the faith of M. Mulot in the correctness of the principle involved, that he determined to continue the work at his own charges. On the 26th of February 1841, the borer suddenly fell several yards, and immediately, from a depth of 1,800 feet, there sprang from the orifice a huge column of water, cold at first but warm afterwards. It now steadily yields more than 740,000 gallons per day. At the first burst the supply was greater.*

These are some of the subjects to which geology lends its aid in promoting our material prosperity, comfort, and health. But its bearings in many other directions extend far and wide. Physical geography, for example, is in reality a branch of geology, for the present forms of sea and land are but the result of all the geological changes to which our globe has been subject, and existing forms of vegetable and animal life are to the present world what the fossil forms in the rocks (and many more unpreserved, or that may never be disentombed,) were to the scenery of the lost continents and islands of bypast epochs. Viewed in this light, geology connects itself with the more graceful arts that at once adorn and elevate society, and that quite independently of the beautiful mineral substances yielded by the rocks for purposes of art. It becomes of value to the artist, for it cannot be quite unimportant to him that he should be ignorant of the origin of the infinite diversities of scenery, of the great operations that have given distinctive features to every plain, and hill, and mountain crag. In many a depicted scene, however skilfully coloured, the geologist who has an eye for art sometimes detects improbable forms or combinations. The sculptor and the historical painter may not safely be ignorant of anatomy, and on the same principle it cannot be a matter of small moment, that, merely copying externals, the landscape painter should be utterly ignorant of the inner anatomy of the scene; for I cannot but believe, that a certain knowledge of this

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* See Le Puits Artésien de Grenelle, par M. Rey. Paris, 1843.

structure will go far to give the impress of a vivid reality to the landscape he delineates, when, abhorring conventional forms of rock and mountain, he, in his compositions, bearing in mind the actual value and relation of all the parts of a landscape as composed by nature, transfers to his canvas the truthful impressions of a well stored and cultivated mind. It is this perfect truthfulness that often lends so exquisite a charm to the works of the greatest English landscape painters of modern times, whose mountains and rocks are so true that the geologist can often pronounce their very nature and their names.

I must now close. In succeeding Lectures it will be one of my aims to inculcate that a sound knowledge of theory is indispensable towards all the applications of geology, whether economic or otherwise. Let not any man consider that when he has mastered the few facts that may be immediately turned to account in money getting, that his geological education is complete. The men who first educed all our great results were mainly actuated by the love of truth alone; and the applications are an accidental fruit of that love. On every possible ground it is, therefore, worse than impolitic to undervalue any truly philosophical work of the geologist, whether it be shown in the unravelment of geological intricacies in the mountains, or in abstract studies in the closet. As a point of conscience actuated by these principles, it has been the aim of those engaged on the geological survey to carry accuracy of scientific detail to the extremest possible limit; and (independently of any immediate benefit to science and to the owners of the soil) who can predict what may yet arise to further the arts of peace from such labours, even in districts apparently the most unprofitable? Let no geologist, therefore, be discouraged because of the sneering cry *cui bono*. The true man of science will not heed it; and hitherto geologists have pursued their ends unscared.

No people has produced so many men eminent in geology as the British Isles. Though not the birth-place of geology, it is here that it has been principally fostered and reared to its present goodly stature, within the memory of many yet living. Of the illustrious men who aided in this work some have

passed away, but others still remain among us; and difficult as it may be to follow in the footsteps or to emulate the "large utterance" of these early giants, I earnestly hope, albeit the signs are few and meagre, that a race may yet spring up not unworthy to be their successors. The links that bind primeval time to our own have to be sought out,—the history of a world has to be unravelled. The alphabet has been discovered, and some of the inscriptions graven on the rocks are deciphered; but many readings are wanting, many passages obscure. The time is still early, the subject is but opening to view, and its revelations are boundless. Hitherto there has been a wonderful unanimity of purpose among all true cultivators of geology. The advance of geology, through the friendly co-operation of its votaries, has known no pause since the decline of the Huttonian and Wernerian controversy. The physical structure of our country is one cause of this rapid progress, but the earnest character of the men who investigated that country is another secret of the strength that has so rapidly urged the science onwards; and I earnestly trust and believe that that strength will know no decay while the rising cultivators of geology continue worthily to follow the bright example set by their great predecessors.

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